APPENDIX B

Antenna (radio)

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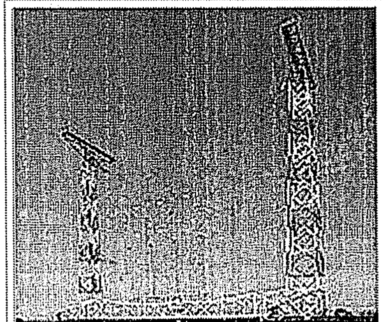


Short Wave "Curtain" Antenna (Moosbrunn, Austria)

An **antenna** is a transducer designed to transmit or receive electromagnetic waves. In other words, antennas convert electromagnetic waves into electrical currents and vice versa. Antennas are used in systems such as radio and television broadcasting, point-to-point radio communication, wireless LAN, radar, and space exploration. Antennas usually work in air or outer space, but can also be operated under water or even through soil and rock at certain frequencies for short distances.

Physically, an antenna is an arrangement of conductors that generate a radiating electromagnetic field in response to an applied alternating voltage and the associated alternating electric current, or can be placed in an electromagnetic field so that the field will induce an alternating current in the antenna and a voltage between its terminals. Some antenna devices (parabolic antenna, Horn Antenna) just adapt the free space to another type of antenna.

Thomas Edison used antennas by 1885. Edison patented his system in U.S. Patent 465,971 (http://patft.uspto.gov/netacgi/nph-Parser?patentnumber=465971) . Antennas were also used in 1888 by Heinrich Hertz (1857-1894) to prove the existence of electromagnetic waves predicted by the theory of James Clerk Maxwell. Hertz placed the emitter dipole in the focal point of a parabolic reflector. He published his work and installation drawings in *Annalen der Physik und Chemie* (vol. 36, 1889).

Contents

Terminology

The words *antenna* (plural: *antennas*[1]) and "aerial" are used interchangeably; but usually a rigid metallic structure is termed an antenna and a wire format is called an aerial. In the United Kingdom and other British English speaking areas the term aerial is more common, even for rigid types. The noun *aerial* is occasionally written with a diaresis mark — *aërial* — in recognition of the original spelling of the adjective *aërial* from which the noun is derived.

The origin of the word *antenna* relative to wireless apparatus is attributed to Guglielmo Marconi. In 1895, while testing early radio apparatus in the Swiss Alps at Salvan, Switzerland in the Mont Blanc region, Marconi experimented with early wireless equipment. A 2.5 meter long pole, along which was carried a wire, was used as a radiating and receiving aerial element. In Italian a tent pole is known as *l'antenna centrale,* and the pole with a wire alongside it used as an aerial was simply called *l'antenna.* Until then wireless radiating transmitting and receiving elements were known simply as aerials or terminals. Marconi's use of the word *antenna* (Italian for *pole*) would become a popular term for what today is uniformly known as the *antenna.*[2]

A Hertzian antenna is a set of terminals that does not require the presence of a ground for its operation (versus a Tesla antenna which is grounded. [3]) A loaded antenna is an active antenna having an elongated portion of appreciable electrical length and having additional inductance or capacitance directly in series or shunt with the elongated portion so as to modify the standing wave pattern existing along the portion or to change the effective electrical length of the portion. An antenna grounding structure is a structure for establishing a reference potential level for operating the active antenna. It can be any structure closely associated with (or acting as) the ground which is connected to the terminal of the signal receiver or source opposing the active antenna terminal (i.e., the signal receiver or source is interposed between the active antenna and this structure).

Overview

Antennas have practical uses for the transmission and reception of radio frequency signals (radio, TV, etc.). In air, those signals travel close to the speed of light in vacuum and with a very low transmission loss. The signals are absorbed when propagating through more conducting materials, such as concrete walls, rock, etc. When encountering an interface, the waves are partially reflected and partially transmitted through.

The vast majority of antennas are simple vertical rods a quarter of a wavelength long. Such antennas are simple in construction, usually inexpensive, and both radiate in and receive from all horizontal directions (omnidirectional). One limitation of this antenna is that it does not radiate or receive in the direction in which the rod points. This region is called the antenna blind cone or null.

There are two fundamental types of antennas, which, with reference to a specific three dimensional (usually horizontal or vertical) plane are either:

1. Omni-directional (radiates equally in all directions), such as a vertical rod or
2. Directional (radiates more in one direction than in the other).

In colloquial usage omni-directional usually refers to all horizontal directions with reception above and below the antenna being reduced in favor of better reception (and thus range) in other directions. Also directional antennas are usually meant to refer to one targeting a single specific direction such as a telescope, satellite dish, or possibly a 120° horizontal reception and transmission area.

All antennas radiate some energy in all directions in free space but careful construction results in substantial transmission of energy in a preferred direction and negligible energy radiated in other directions.

By adding additional conducting rods or coils (called *elements*) and varying their length, spacing, and orientation (or changing the direction of the antenna beam), an antenna with specific desired properties can be created, such as a Yagi-Uda Antenna (often abbreviated to "Yagi").

An antenna array is two or more antennas coupled to a common source or load to produce a specific directional radiation pattern. The spatial relationship between individual antennas contributes to the directivity of the antenna.

The term active element is intended to describe an element whose energy output is modified due to the presence of a source of energy in the element (other than the mere signal energy which passes through the circuit) or an element in which the energy output from a source of energy is controlled by the signal input.

An antenna lead-in is the medium, for example, a transmission line or feed line for conveying the signal energy between the signal source or receiver and the antenna. The antenna feed refers to the components between the antenna and an amplifier.

An antenna counterpoise is a structure of conductive material most closely associated with ground that may be insulated from or capacitively coupled to the natural ground. It aids in the function of the natural ground, particularly where variations (or limitations) of the characteristics of the natural ground interfere with its proper function. Such structures are usually connected to the terminal of a receiver or source opposite to the antenna terminal.

An antenna component is a portion of the antenna performing a distinct function and limited for use in an antenna, as for example, a reflector, director, or active antenna.

Parasitic elements are usually metallic conductive structures which reradiate into free space impinging electromagnetic radiation coming from or going to the active antenna.

An electromagnetic wave refractor is a structure which is shaped or positioned to delay or accelerate

transmitted electromagnetic waves, passing through such structure, an amount which varies over the wave front. The refractor alters the direction of propagation of the waves emitted from the structure with respect to the waves impinging on the structure. It can alternatively bring the wave to a focus or alter the wave front in other ways, such as to convert a spherical wave front to a planar wave front (or vice versa). The velocity of the waves radiated have a component which is in the same direction (director) or in the opposite direction (reflector) as that of the velocity of the impinging wave.

A director is usually a metallic conductive structure which reradiates into free space impinging electromagnetic radiation coming from or going to the active antenna, the velocity of the reradiated wave having a component in the direction of the velocity of the impinging wave. The director modifies the radiation pattern of the active antenna and there is no significant potential relationship between the active antenna and this conductive structure.

A reflector is usually a metallic conductive structure (e.g., screen, rod or plate) which reradiates back into free space impinging electromagnetic radiation coming from or going to the active antenna. The velocity of the returned wave having a component in a direction opposite to the direction of the velocity of the impinging wave. The reflector modifies the radiation of the active antenna. There is no significant potential relationship between the active antenna and this conductive structure.

An antenna coupling network is a passive network (which may be any combination of a resistive, inductive or capacitive circuit(s)) for transmitting the signal energy between the active antenna and a source (or receiver) of such signal energy.

Typically, antennas are designed to operate in a relatively narrow frequency range. The design criteria for receiving and transmitting antennas differ slightly, but generally an antenna can receive and transmit equally well. This property is called reciprocity.

Parameters

There are several critical parameters affecting an antenna's performance that can be adjusted during the design process. These are resonant frequency, impedance, gain, aperture or radiation pattern, polarization, efficiency and bandwidth. Transmit antennas may also have a maximum power rating, and receive antennas differ in their noise rejection properties. All of these parameters can be measured through various means.

Resonant frequency

The "*resonant frequency*" and "*electrical resonance*" is related to the electrical length of an antenna. The electrical length is usually the physical length of the wire divided by its velocity factor (the ratio of the speed of wave propagation in the wire to c_0, the speed of light in a vacuum). Typically an antenna is tuned for a specific frequency, and is effective for a range of frequencies that are usually centered on that resonant frequency. However, other properties of an antenna change with frequency, in particular the radiation pattern and impedance, so the antenna's resonant frequency may merely be close to the center frequency of these other more important properties.

Antennas can be made resonant on harmonic frequencies with lengths that are fractions of the target wavelength. Some antenna designs have multiple resonant frequencies, and some are relatively effective over a very broad range of frequencies. The most commonly known type of wide band aerial is the

logarithmic or log periodic, but its gain is usually much lower than that of a specific or narrower band aerial.

Gain

Gain as a parameter measures the directionality of a given antenna. An antenna with a low gain emits radiation with about the same power in all directions, whereas a high-gain antenna will preferentially radiate in particular directions. Specifically, the **Gain, Directive gain** or **Power gain** of an antenna is defined as the ratio of the intensity (power per unit surface) radiated by the antenna in a given direction at an arbitrary distance divided by the intensity radiated at the same distance by a hypothetical isotropic antenna.

The gain of an antenna is a passive phenomenon - power is not added by the antenna, but simply redistributed to provide more radiated power in a certain direction than would be transmitted by an isotropic antenna. If an antenna has a greater than one gain in some directions, it must have a less than one gain in other directions since energy is conserved by the antenna. An antenna designer must take into account the application for the antenna when determining the gain. High-gain antennas have the advantage of longer range and better signal quality, but must be aimed carefully in a particular direction. Low-gain antennas have shorter range, but the orientation of the antenna is inconsequential. For example, a dish antenna on a spacecraft is a high-gain device that must be pointed at the planet to be effective, whereas a typical Wi-Fi antenna in a laptop computer is low-gain, and as long as the base station is within range, the antenna can be in an any orientation in space. It makes sense to improve horizontal range at the expense of reception above or below the antenna. Thus most antennas labelled "omnidirectional" really have some gain.[4]

Sometimes, the half-wave dipole is taken as a reference instead of the isotropic radiator. The gain is then given in **dBd** (decibels over **d**ipole):

0 dBd = 2.15 dBi

Radiation pattern

The radiation pattern of an antenna is the geometric pattern of the relative field strengths of the field emitted by the antenna. For the ideal isotropic antenna, this would be a sphere. For a typical dipole, this would be a toroid. The radiation pattern of an antenna is typically represented by a three dimensional graph, or polar plots of the horizontal and vertical cross sections. The graph should show sidelobes and backlobes, where the antenna's gain is at a minima or maxima.

See Antenna measurement: Radiation pattern or Radiation pattern for more information.

Impedance

As an electro-magnetic wave travels through the different parts of the antenna system (radio, feed line, antenna, free space) it may encounter differences in impedance (E/H, V/I, etc). At each interface, depending on the impedance match, some fraction of the wave's energy will reflect back to the source[5], forming a standing wave in the feed line. The ratio of maximum power to minimum power in the wave can be measured and is called the standing wave ratio (**SWR**). A SWR of 1:1 is ideal. A SWR of 1.5:1 is considered to be marginally acceptable in low power applications where power loss is more critical,

although an SWR as high as 6:1 may still be usable with the right equipment. Minimizing impedance differences at each interface (impedance matching) will reduce SWR and maximize power transfer through each part of the antenna system.

Complex impedance of an antenna is related to the electrical length of the antenna at the wavelength in use. The impedance of an antenna can be matched to the feed line and radio by adjusting the impedance of the feed line, using the feed line as an impedance transformer. More commonly, the impedance is adjusted at the load (see below) with an antenna tuner, a balun, a matching transformer, matching networks composed of inductors and capacitors, or matching sections such as the gamma match.

Efficiency

Efficiency is the ratio of power actually radiated to the power put into the antenna terminals. A dummy load may have an SWR of 1:1 but an efficiency of 0, as it absorbs all power and radiates heat but not RF energy, showing that SWR alone is not an effective measure of an antenna's efficiency. Radiation in an antenna is caused by radiation resistance which can only be measured as part of total resistance including loss resistance. Loss resistance usually results in heat generation rather than radiation, and reduces efficiency. Mathematically, efficiency is calculated as radiation resistance divided by total resistance.

Bandwidth

The *bandwidth* of an antenna is the range of frequencies over which it is effective, usually centered on the resonant frequency. The bandwidth of an antenna may be increased by several techniques, including using thicker wires, replacing wires with *cages* to simulate a thicker wire, tapering antenna components (like in a feed horn), and combining multiple antennas into a single assembly and allowing the natural impedance to select the correct antenna. Small antennas are usually preferred for convenience, but there is a fundamental limit relating bandwidth, size and efficiency.

Polarization

The *polarization* of an antenna is the orientation of the electric field (E-plane) of the radio wave with respect to the Earth's surface and is determined by the physical structure of the antenna and by its orientation. It has nothing in common with antenna directionality terms: "horizontal", "vertical" and "circular". Thus, a simple straight wire antenna will have one polarization when mounted vertically, and a different polarization when mounted horizontally. "Electromagnetic wave polarization filters" are structures which can be employed to act directly on the electromagnetic wave to filter out wave energy of an undesired polarization and to pass wave energy of a desired polarization.

Reflections generally affect polarization. For radio waves the most important reflector is the ionosphere - signals which reflect from it will have their polarization changed unpredictably. For signals which are reflected by the ionosphere, polarization cannot be relied upon. For line-of-sight communications for which polarization can be relied upon, it can make a large difference in signal quality to have the transmitter and receiver using the same polarization; many tens of dB difference are commonly seen and this is more than enough to make the difference between reasonable communication and a broken link.

Polarization is largely predictable from antenna construction but, especially in directional antennas, the polarization of side lobes can be quite different from that of the main propagation lobe. For radio antennas, polarization corresponds to the orientation of the radiating element in an antenna. A vertical

omnidirectional WiFi antenna will have vertical polarization (the most common type). An exception is a class of elongated waveguide antennas in which vertically placed antennas are horizontally polarized. Many commercial antennas are marked as to the polarization of their emitted signals.

Polarization is the sum of the E-plane orientations over time projected onto an imaginary plane perpendicular to the direction of motion of the radio wave. In the most general case, polarization is elliptical (the projection is oblong), meaning that the antenna varies over time in the polarization of the radio waves it is emitting. Two special cases are linear polarization (the ellipse collapses into a line) and circular polarization (in which the ellipse varies maximally). In linear polarization the antenna compels the electric field of the emitted radio wave to a particular orientation. Depending on the orientation of the antenna mounting, the usual linear cases are horizontal and vertical polarization. In circular polarization, the antenna continuously varies the electric field of the radio wave through all possible values of its orientation with regard to the Earth's surface. Circular polarizations, like elliptical ones, are classified as right-hand polarized or left-hand polarized using a "thumb in the direction of the propagation" rule. Optical researchers use the same rule of thumb, but pointing it in the direction of the emitter, not in the direction of propagation, and so are opposite to radio engineers' use.

In practice, regardless of confusing terminology, it is important that linearly polarized antennas be matched, lest the received signal strength be greatly reduced. So horizontal should be used with horizontal and vertical with vertical. Intermediate matchings will lose some signal strength, but not as much as a complete mismatch. Transmitters mounted on vehicles with large motional freedom commonly use circularly polarized antennas so that there will never be a complete mismatch with signals from other sources. In the case of radar, this is often reflections from rain drops.

Transmission and reception

All of the antenna parameters are expressed in terms of a transmission antenna, but are identically applicable to a receiving antenna, due to reciprocity. Impedance, however, is not applied in an obvious way; for impedance, the impedance at the load (where the power is consumed) is most critical. For a transmitting antenna, this is the antenna itself. For a receiving antenna, this is at the (radio) receiver rather than at the antenna. Tuning is done by adjusting the length of an electrically long linear antenna to alter the electrical resonance of the antenna.

Antenna tuning is done by adjusting an inductance or capacitance combined with the active antenna (but distinct and separate from the active antenna). The inductance or capacitance provides the reactance which combines with the inherent reactance of the active antenna to establish a resonance in a circuit including the active antenna. The established resonance being at a frequency other than the natural electrical resonant frequency of the active antenna. Adjustment of the inductance or capacitance changes this resonance.

Antennas used for transmission have a maximum power rating, beyond which heating, arcing or sparking may occur in the components, which may cause them to be damaged or destroyed. Raising this maximum power rating usually requires larger and heavier components, which may require larger and heavier supporting structures. This is a concern only for transmitting antennas, as the power received by an antenna rarely exceeds the microwatt range.

Antennas designed specifically for reception might be optimized for noise rejection capabilities. An *antenna shield* is a conductive or low reluctance structure (such as a wire, plate or grid) which is adapted to be placed in the vicinity of an antenna to reduce, as by dissipation through a resistance or by

conduction to ground, undesired electromagnetic radiation, or electric or magnetic fields, which are directed toward the active antenna from an external source or which emanate from the active antenna. Other methods to optimize for noise rejection can be done by selecting a narrow bandwidth so that noise from other frequencies is rejected, or selecting a specific radiation pattern to reject noise from a specific direction, or by selecting a polarization different from the noise polarization, or by selecting an antenna that favors either the electric or magnetic field.

For instance, an antenna to be used for reception of low frequencies (below about ten megahertz) will be subject to both man-made noise from motors and other machinery, and from natural sources such as lightning. Successfully rejecting these forms of noise is an important antenna feature. A small coil of wire with many turns is more able to reject such noise than a vertical antenna. However, the vertical will radiate much more effectively on transmit, where extraneous signals are not a concern.

Basic antenna models

There are many variations of antennas. Below are a few basic models. More can be found in Category:Radio frequency antenna types.

- The isotropic radiator is a purely theoretical antenna that radiates equally in all directions. It is considered to be a point in space with no dimensions and no mass. This antenna cannot physically exist, but is useful as a theoretical model for comparison with all other antennas. Most antennas' gains are measured with reference to an isotropic radiator, and are rated in dBi (decibels with respect to an isotropic radiator).
- The dipole antenna is simply two wires pointed in opposite directions arranged either horizontally or vertically, with one end of each wire connected to the radio and the other end hanging free in space. Since this is the simplest practical antenna, it is also used as a reference model for other antennas; gain with respect to a dipole is labeled as dBd. Generally, the dipole is considered to be omnidirectional in the plane perpendicular to the axis of the antenna, but it has deep nulls in the directions of the axis. Variations of the dipole include the folded dipole, the half wave antenna, the ground plane antenna, the whip, and the J-pole.
- The Yagi-Uda antenna is a directional variation of the dipole with parasitic elements added with functionality similar to adding a reflector and lenses (directors) to focus a filament light bulb.
- The random wire antenna is simply a very long (at least one quarter wavelength) wire with one end connected to the radio and the other in free space, arranged in any way most convenient for the space available. Folding will reduce effectiveness and make theoretical analysis extremely difficult. (The added length helps more than the folding typically hurts.) Typically, a random wire antenna will also require an antenna tuner, as it might have a random impedance that varies nonlinearly with frequency.
- The Horn is used where high gain is needed, the wavelength is short (microwave) and space is not an issue. Horns can be narrow band or wide band, depending on their shape. A horn can be built for any frequency, but horns for lower frequencies are typically impractical. Horns are also frequently used as reference antennas.

Practical antennas

Although any circuit can radiate if driven with a signal of high enough frequency, most practical antennas are specially designed to radiate efficiently at a particular frequency. An example of an inefficient antenna is the simple Hertzian dipole antenna, which radiates over wide range of frequencies and is

useful for its small size. A more efficient variation of this is the half-wave dipole, which radiates with high efficiency when the signal wavelength is twice the electrical length of the antenna.

One of the goals of antenna design is to minimize the reactance of the device so that it appears as a resistive load. An "antenna inherent reactance" includes not only the distributed reactance of the active antenna but also the natural reactance due to its location and surroundings (as for example, the capacity relation inherent in the position of the active antenna relative to ground). Reactance diverts energy into the reactive field, which causes unwanted currents that heat the antenna and associated wiring, thereby wasting energy without contributing to the radiated output. Reactance can be eliminated by operating the antenna at its resonant frequency, when its capacitive and inductive reactances are equal and opposite, resulting in a net zero reactive current. If this is not possible, compensating inductors or capacitors can instead be added to the antenna to cancel its reactance as far as the source is concerned.

Once the reactance has been eliminated, what remains is a pure resistance, which is the sum of two parts: the ohmic resistance of the conductors, and the radiation resistance. Power absorbed by the ohmic resistance becomes waste heat, and that absorbed by the radiation resistance becomes radiated electromagnetic energy. The greater the ratio of radiation resistance to ohmic resistance, the more efficient the antenna.

Effect of ground

Antennas are typically used in an environment where other objects are present that may have an effect on their performance. Height above ground has a very significant effect on the radiation pattern of some antenna types.

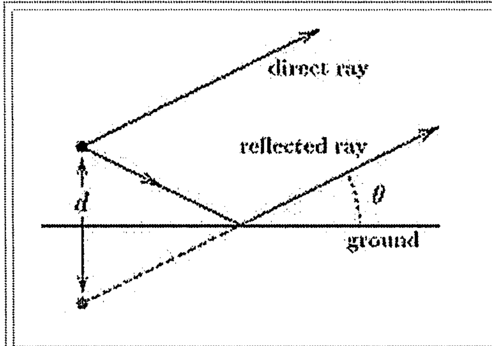
At frequencies used in antennas, the ground behaves mainly as a dielectric. The conductivity of ground at these frequencies is negligible. When an electromagnetic wave arrives at the surface of an object, two waves are created: one enters the dielectric and the other is reflected. If the object is a conductor, the transmitted wave is negligible and the reflected wave has almost the same amplitude as the incident one. When the object is a dielectric, the fraction reflected depends (among others things) on the angle of incidence. When the angle of incidence is small (that is, the wave arrives almost perpendicularly) most of the energy traverses the surface and very little is reflected. When the angle of incidence is near 90° (grazing incidence) almost all the wave is reflected.

Most of the electromagnetic waves emitted by an antenna to the ground below the antenna at moderate (say < 60°) angles of incidence enter the earth and are absorbed (lost). But waves emitted to the ground at grazing angles, far from the antenna, are almost totally reflected. At grazing angles, the ground behaves as a mirror. Quality of reflection depends on the nature of the surface. When the irregularities of the surface are smaller than the wavelength reflection is good.

This means that the receptor "sees" the real antenna and, under the ground, the image of the antenna reflected by the ground. If the ground has irregularities, the image will appear fuzzy.

If the receiver is placed at some height above the ground, waves reflected by ground will travel a little longer distance to arrive to the receiver than direct waves. The distance will be the same only if the receiver is close to ground.

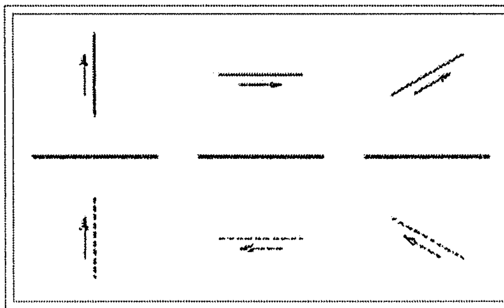
In the drawing at right, we have drawn the angle θ far bigger than in reality. Distance between the antenna and its image is d.



The wave reflected by earth can be considered as emitted by the image antenna

The situation is a bit more complex because the reflection of electromagnetic waves depends on the polarization of the incident wave. As the refractive index of the ground (average value $\simeq 2$) is bigger than the refractive index of the air ($\simeq 1$), the direction of the component of the electric field parallel to the ground inverses at the reflection. This is equivalent to a phase shift of π radians or 180°. The vertical component of the electric field reflects without changing direction. This sign inversion of the parallel component and the non-inversion of the perpendicular component would also happen if the ground were a good electrical conductor.

This means that a receiving antenna "sees" the image antenna with the current in the same direction if the antenna is vertical or with the current inverted if the antenna is horizontal.



The vertical component of the current reflects without changing sign. The horizontal component reverses sign at reflection.

For a vertical polarized emission antenna the far electric field of the electromagnetic wave produced by the direct ray plus the reflected ray is:

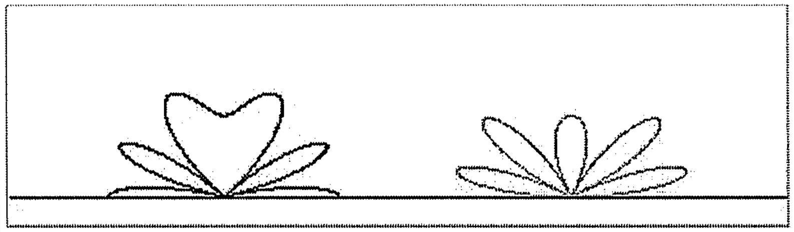
$$\left|E_{\perp}\right| = 2\left|E_{\theta_1}\right|\left|\cos\left(\frac{kd}{2}\sin\theta\right)\right|$$

The sign inversion for the parallel field case just changes a cosine to a sine:

$$\left|E_{=}\right| = 2\left|E_{\theta_1}\right|\left|\sin\left(\frac{kd}{2}\sin\theta\right)\right|$$

In these two equations:

- E_{θ_1} is the electrical field radiated by the antenna if there were no ground.
- $k=\frac{2\pi}{\lambda}$ is the wave number.
- λ is the wave length.
- d is the distance between antenna and its image (twice the height of the center of the antenna).



Radiation patterns of antennas and their images reflected by the ground. At left the polarization is vertical and there is always a maximum for $\theta = 0$. If the polarization is horizontal as at right, there is always a zero for $\theta = 0$.

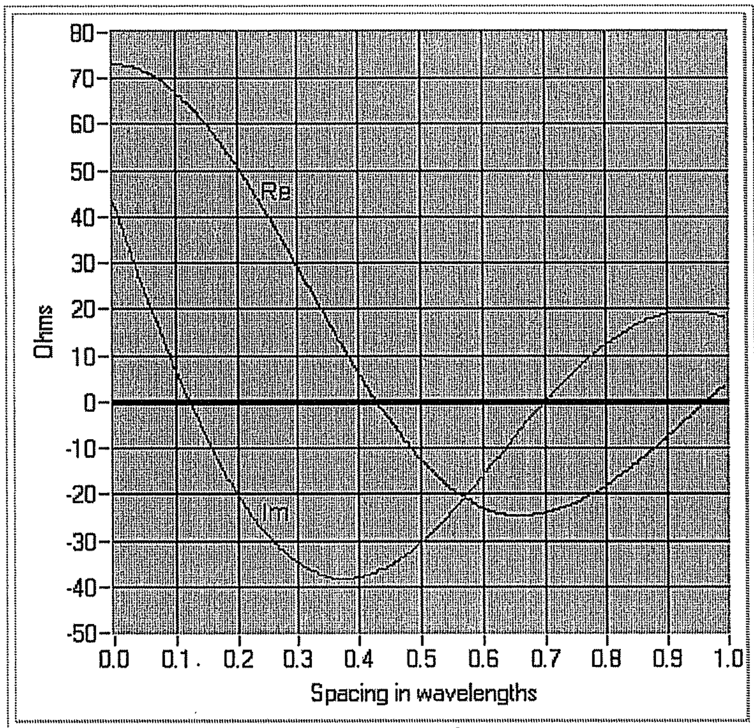
For emitting and receiving antenna situated near the ground (in a building or on a mast) far from each other, distances traveled by direct and reflected rays are nearly the same. There is no induced phase shift. If the emission is polarized vertically the two fields (direct and reflected) add and there is maximum of received signal. If the emission is polarized horizontally the two signals subtracts and the received signal is minimum. This is depicted in the image at right. In the case of vertical polarization, there is always a maximum at earth level (left pattern). For horizontal polarization, there is always a minimum at earth level. Note that in these drawings the ground is considered as a perfect mirror, even for low angles of incidence. In these drawings the distance between the antenna and its image is just a few wavelengths. For greater distances, the number of lobes increases.

Note that the situation is different – and more complex – if reflections in the ionosphere occur. This happens over very long distances (thousands of kilometers). There is not a direct ray but several reflected rays that add with different phase shifts.

This is the reason why almost all public address radio emissions have vertical polarization. As public users are near ground, horizontal polarized emissions would be poorly received. Observe household and automobile radio receivers. They all have vertical antennas or horizontal ferrite antennas for vertical polarized emissions. In cases where the receiving antenna must work in any position, as in mobile phones, the emitter and receivers in base stations use circular polarized electromagnetic waves.

Classical (analog) television emissions are an exception. They are almost always horizontally polarized, because the presence of buildings makes it unlikely that a good emitter antenna image will appear. However, these same buildings reflect the electromagnetic waves and can create ghost images. Using horizontal polarization, reflections are attenuated because of the low reflection of electromagnetic waves whose magnetic field is parallel to the dielectric surface near the Brewster's angle. Vertically polarized analog television has been used in some rural areas. In digital terrestrial television reflections are less annoying because of the type of modulation.

Mutual impedance and interaction between antennas



Mutual impedance between parallel $\frac{\lambda}{2}$ dipoles not staggered. Curves **Re** and **Im** are the resistive and reactive parts of the impedance.

Current circulating in any antenna induces currents in all others. One can postulate a **mutual impedance** Z_{12} between two antennas that has the same significance as the $j\omega M$ in ordinary coupled inductors. The mutual impedance Z_{12} between two antennas is defined as:

$$Z_{12} = \frac{v_2}{i_1}$$

where i_1 is the current flowing in antenna 1 and v_2 is the voltage that would have to be applied to antenna 2 – with antenna 1 removed – to produce the current in the antenna 2 that was produced by antenna 1.

From this definition, the currents and voltages applied in a set of coupled antennas are:

$$\begin{array}{ccccccccc} v_1 & = & i_1 Z_{11} & + & i_2 Z_{12} & + & \cdots & + & i_n Z_{1n} \\ v_2 & = & i_1 Z_{21} & + & i_2 Z_{22} & + & \cdots & + & i_n Z_{2n} \\ \vdots & & \vdots & & \vdots & & & & \vdots \\ v_n & = & i_1 Z_{n1} & + & i_2 Z_{n2} & + & \cdots & + & i_n Z_{nn} \end{array}$$

where:

- v_i is the voltage applied to the antenna *i*
- Z_{ii} is the impedance of antenna *i*
- Z_{ij} is the mutual impedance between antennas *i* and *j*

Note that, as is the case for mutual inductances,

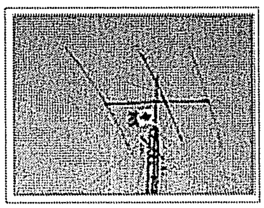
$$Z_{ij} = Z_{ji}$$

If some of the elements are not fed (there is a short circuit instead a feeder cable), as is tl television antennas (Yagi-Uda antennas), the corresponding v_i are zero. Those elements parasitic elements. Parasitic elements are unpowered elements that either reflect or absoı liate RF energy.

In some geometrical settings, the mutual impedance between antennas can be zero. This ior crossed dipoles used in circular polarization antennas.

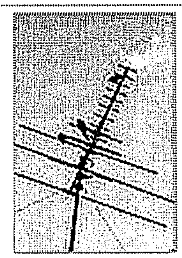
Antenna gallery

Antennas and antenna arrays



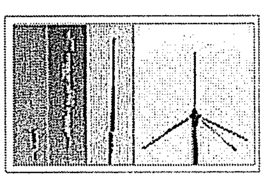
A Yagi-Uda beam antenna.

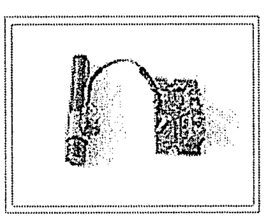
A multi-band rotary directional antenna for amateur radio use.

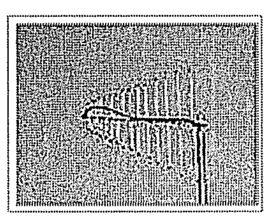


Rooftop television antenna. It is actually three Yagi antennas in one. The longest elements are for the low band (channels 2-6 (1-6 in the UK)) the medium-length elements are for the high band (channels 7-13) and the shortest elements are for the UHF band (channels 14-69 (21-68 in the UK)).

A terrestrial radio antenr







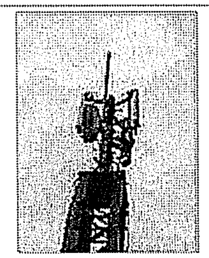
Examples of US 136-174 MHz base station antennas.

Low cost LF time signal receiver, antenna (left) and receiver (right).

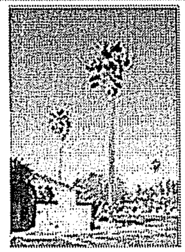
Rotatable log-periodic array for VHF and UHF.

Antennas and supporting structures

A building rooftop supporting numerous dish and sectored mobile telecommunications antennas (Doncaster, Victoria, Australia.

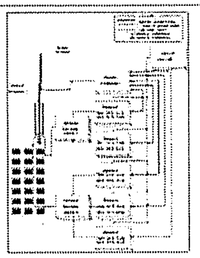


A three-sector telephone site in Mexico City.

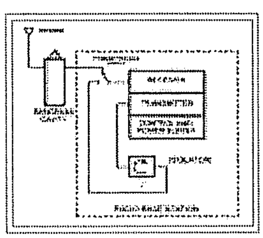


Telephone site concealed as a palm tree.

Diagrams as part of a system



Antennas may be connected through a multiplexing arrangement in some applications like this trunked two-way radio example.



Antenna network for an emergency medical services base station.

See also

- Category:Radio frequency antenna types
- Category:Radio frequency propagation
- Numerical Electromagnetics Code
- Amateur radio
- Antenna Measurements
- Cellular repeater
- Electromagnetism
- Mobile modem
- RF connector
- Radio telescope
- Satellite television
- TETRA
- Wi-Fi
- Smart antenna

Radio portal

Notes

1. ^ In the context of engineering and physics, the plural of *antenna* is *antennas*, and it has been this way since about 1950 (or earlier), when a cornerstone textbook in this field, *Antennas,* was published by John D. Kraus of the Ohio State University. Besides the title, Dr. Kraus noted this in a footnote on the first page of his book. Insects may have "antennae," but this form is not used in technical contexts.
2. ^ *"Salvan: Cradle of Wireless, How Marconi Conducted Early Wireless Experiments in the Swiss Alps", Fred Gardiol & Yves Fournier, Microwave Journal, February 2006, pp. 124-136.*
3. ^ Nikola Tesla said during the development of radio that "*One of the terminals of the source would be connected to Earth* [as a electric ground connection ...] *the other to an insulated body of large surface.* For more information, see "*On Light and Other High Frequency Phenomena (http://www.tfcbooks.com/tesla/1893-02-24.htm)* ". Delivered before the Franklin Institute, Philadelphia, February 1893, and before the National Electric Light Association, St. Louis, Missouri, March 1893.
4. ^ "Guide to Wi-Fi Wireless Network Antenna Selection. (http://networkbits.net/wireless-printing/wireless-network-antenna-guide/) ". NetworkBits.net. Retrieved on 2008-04-08.
5. ^ Impedance is caused by the same physics as refractive index in optics, although impedance effects are typically one dimensional, where effects of refractive index is three dimensional.

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Categories: Antennas (radio) | Radio electronics